CHALLENGES AND SOLUTIONS FOR THE MECHANICAL DESIGN OF SOLEIL-II

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Abstract

The Synchrotron SOLEIL is a large-scale research facility in France that provides synchrotron radiation from terahertz to hard X-rays for various scientific applications. To meet the evolving needs of the scientific community and to remain competitive with other European facilities, SOLEIL has planned an upgrade project called SOLEIL-II. The project aims to reconstruct the storage ring as a Diffraction Limited Storage Ring (DLSR) with a record low emittance which will enable nanometric resolution.

The mechanical design of the upgrade project involves several challenges such as the integration of new magnets, vacuum chambers, insertion devices and beamlines in the existing infrastructure, the optimization of the alignment and stability of the components, and the minimization of the downtime during the transition from SOLEIL to SOLEIL-II. The mechanical design is mainly based on extensive simulations, prototyping, and testing to ensure the feasibility, reliability, and performance of several key elements.

INTRODUCTION

SOLEIL is the French third generation light source operated for users since 2008 with an electron beam emittance of 4 nm·rad at an energy of 2.75 GeV in high intensity (500 mA, multibunch) [1].

The current lattice of the SOLEIL storage ring is composed of 16 modified two-bend achromat cells, 8 of which have short straight sections between the dipoles, altogether giving a total of 24 straight sections. After years of successful operation, a series of feasibility studies were initiated for a possible upgrade of the storage ring with a significantly lower emittance.

The SOLEIL Upgrade project, known as SOLEIL-II aims to design and build a 2.75 GeV diffraction-limited synchrotron light source preserving the actual infrastructure, 29 beamlines (far-IR to hard X-rays) and the 500 mA uniform filling pattern. The lattice of the new storage ring presented in CDR report [1] is built over a non-standard combination of twelve 7BA cells and eight 4BA cells [2, 3]. The main comparison parameters are listed in Table 1.

Table 1: Main SOLEIL-II Lattice Parameters

	Actual	**Upgrade**
Emittance (2.75 GeV)	4 nm·rad	84 pm·rad
Circumference	354.1 m	353.5 m
Straight section number	24	20
Long straight length	12 m	8.0/8.3 m
Medium straight length	7 m	4.25 m
Short straight length	3.8 m	3.0 m

Figure 1 shows the arrangement of the magnets in the 7BA cell and the 4BA cell of SOLEIL-II lattice. The length of the 7BA cell is rather short (~16 m) containing 52 magnets, depending on the lattice version, and including 7 dipoles. This very high density of multipoles increases the problem of compactness and creates implementation difficulties.

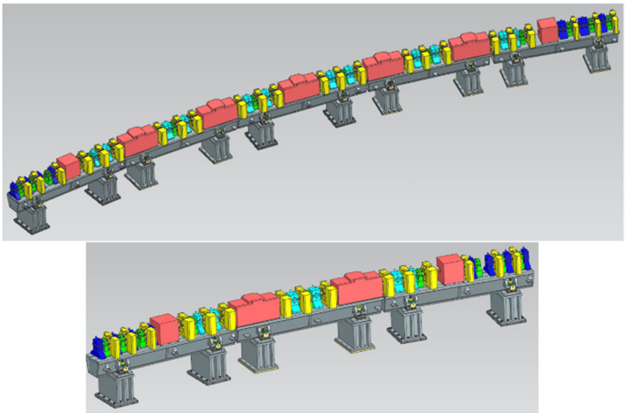

Figure 1: Engineering layout of the 7BA cell type of the new MBA-ARC (top) and the 4BA cell (bottom).

GIRDER DESIGN

The design of the girders is the result of a compromise between the vibration and thermal stability, adjustment precision and overall fabrication costs. After few iterations, SOLEIL mechanical engineers came up with a design based on four girder length families. Each girder family can be assembled in different configurations carrying single or double dipole [4].

The specification defined by accelerator physicists for the first modal frequency is around 40 Hz under load. Figure 2 shows the FE simulations on one of girder families in two different configurations.

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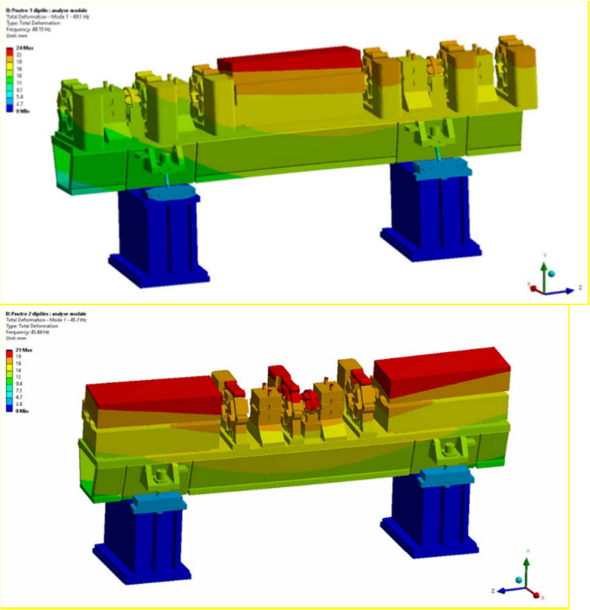

Figure 2: 1st modal frequency at 49 Hz in single dipole configuration (top) and 45 Hz in double dipole configuration (bottom).

Special toolings have been developed to extract dipoles from the girder without touching the vacuum chamber. Figure 3 shows the operation sequences: dipole at its initial position on the girder (Fig. 3 top-left), assembly of the tooling (Fig. 3 top-right), sliding parts assembly on the dipole (Fig. 3 bottom-left), lifting the dipole and slide it aside (Fig. 3 bottom-right) [5].

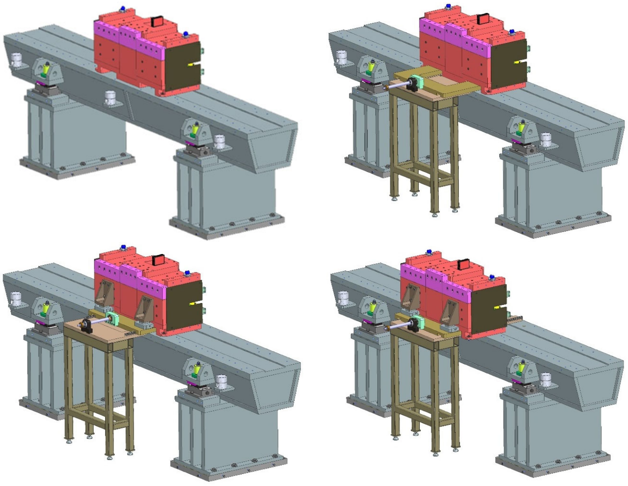

Figure 3: Retracting scenario of a dipole from the girder (from top-left to bottom right).

VACUUM SYSTEM

The main challenge designing SOLEIL-II vacuum system is the extreme compactness of the layout. In most cases, there is less than 60 mm between multipoles. The standard vcuum chamber diameter is 12 mm in achromat cells. The goal is to have a full distributed Ti-Zr-V NEG coating of 0.5 µm average thickness covering almost 100% of the internal surface. The NEG pumping system will be activated by ex-situ bake-out.

In addition to the NEG coating, one standard ion pump will be foreseen after each dipole near to the crotch absorber (see Fig. 4).

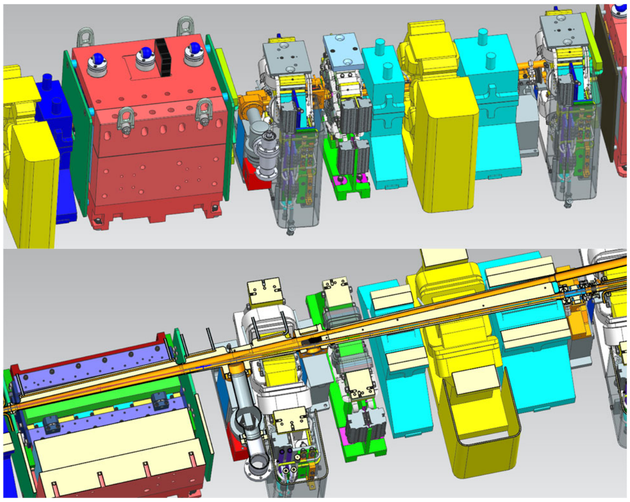

Figure 4: DNC short dipole vacuum chamber implementation in the restraint environment.

The vacuum system will be mainly fabricated in CuCr1Zr or OFHC copper. All parts in stainless steel will be coated by 10 µm copper or silver to reduce the impedance. In order to guarantee the RF continuity, two different kinds of gaskets will be used: MO type [6] for smaller diameter (12-16 mm) and CF-RF for larger diameters (see Fig. 5).

Figure 5: MO-type copper gasket (left) and CF-RF gasket (right).

The same philosophy has been used for RF bellows. In the achromat, a comb-type bellows is under prototyping. This kind of bellows has a limited stroke (few mm) and small lateral flexibility but an excellent RF contact. A classic RF finger bellows will be used in straight sections where more flexibility is needed (see Fig. 6).

In downstream of each dipole, an absorber bloc in CuCr1Zr is inserted containing two crotch absorbers (upper and lower crotch) and a sputtering ion pump. The deviation angle of the short dipoles on SOLEIL-II lattice is only around 2°. Thus, the distance between the photon beam and the electron beam does not exceed ~30 mm. small crotch absorbers based on additive manufacturing (AM) procedure have been designed at this location. The cooling channels have been optimized to reduces maximum temperature, comparing to a crotch fabricated in a classical way, by more than 30 °C (see Fig. 7).

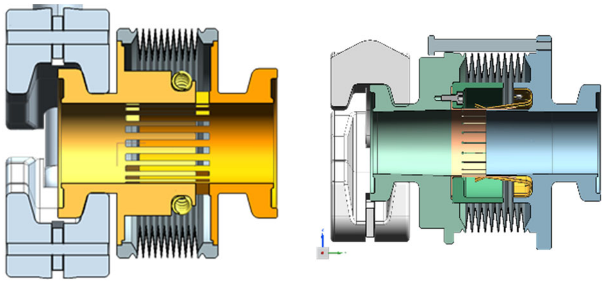

Figure 6: Comb-type bellows (left) and RF-finger based bellows design (right).

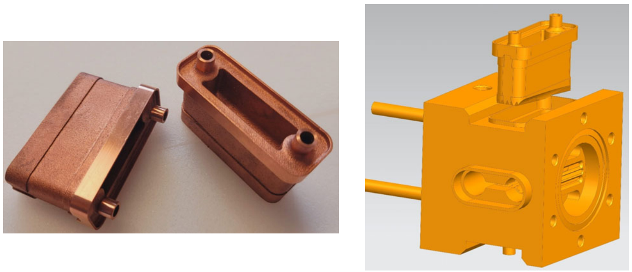

Figure 7: CuCr1Zr Additive manufacturing crotch (left) inserted and welded on the absorber bloc (right).

CONCLUSION

SOLEIL II is an ambitious project, promising very high performance, but is not without its challenges. A Machine Advisory Committee (MAC) has been established with a mandate lasting for three years 2022–2024. The project could get the ‘green light’ in autumn 2023, which could provide some preliminary funding in 2024, and allow the placing of some orders with payments due in 2025 and beyond.

The extreme compactness of the layout pushes the mechanical engineers to use innovative solutions and emerging technologies like copper alloys powder metallurgy additive fabrication. Many prototypes are under study, fabrication or already under qualification.

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